

Field Evaluation of a New Prototype Self-Contained Breathing Apparatus

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Study Objective

To evaluate and compare a prototype low profile self-contained breathing apparatus (SCBA) prototype (PA) to a standard SCBA (SA) as assessed by objective /subjective measures of mobility and comfort, time of donning/doffing, and from subjects' input on the design features.

Introduction

- It is well established that firefighter protective ensembles are heavy and cumbersome and impose an ergonomic “burden” on the wearer. The use of an SCBA, while providing essential respiratory protection, further adds to the weight of the ensemble and ergonomic burden.
- A new prototype low-profile SCBA (MSA, Pittsburgh, PA), was developed to provide reduced weight, lower profile (limit entanglement and improve access to confined space), and flexibility while being worn with a standard ensemble.

Materials and Methods

- The PA (Figures 1-2) consisted of an assembly of 5 connected pressure vessels constructed from a high temperature pressure vessel lining constructed using a special lining covered with braided Kevlar® and wound with pre-impregnated carbon fiber. The entire assembly is secured inside a soft flexible cover allowing the pressure vessel assembly to flex to accommodate the movement of the wearer. The pressure vessels are rated at 4500 psi which supplies the same volume as a conventional 45 minute-rated SCBA. The PA assembly weighs 12.1 kg (empty) and is 76 × 33 × 10 (H×W×D; cm).
- The SA (Figure 2) weighs 13.07 (empty) and is 60 × 25 × 20 (H×W×D; cm)
- During the testing at Prince George’s County Fire Academy, MD subjects (Table 1) wore standard structural firefighter ensemble consisting of the helmet, turnout jacket, pants, gloves, and boots and either the SA or PA and carried other necessary tools/equipment provided at each test station. Both the PA and SA were empty during this evaluation.
- The experimental protocol consisted of an ergonomic evaluation and five field exercises at separate training stations, designed to simulate activities that fire fighters encounter on duty. These activities are based on the IAFF Fire Ground Survival program
 - Station 1- Ergonomics evaluation
 - Station 2 - Reduce profile exercise
 - Station 3 - Window egress exercise (Figure 3)
 - Station 4 - Entanglement exercise
 - Station 5 - SCBA confidence course
 - Station 6 - Roof venting exercise (Figure 4)
- Static and dynamic range of motion (ROM) measurements were made in Station 1: shoulder flexion/abduction, cervical rotation/flexion/extension, trunk flexion/extension/lateral flexion, stand and reach, overhead reach, and donning/doffing time.



Figure 1. Low profile SCBA



Figure 2 . PA (middle) worn by Subject, SA (left and right)

Materials and Methods (continued)

Table 1 – Subject Characteristics

Subject Gender / Occupation	Age (yr)	Height (cm)	Body Mass (kg)
Male (12 firefighters, 2 law enforcement)	35.9±8.3	173.5±19.8	89±11.4
Female (2 firefighters)	35±7.9	169.7±6.3	65±5.6

- Measurements were made with a Goniometer (a type of protractor for measurement of angles), torso bend device (Acuflex I, Novel Products, Inc., Rockton, IL), multi-colored tape (for marking purposes), tape measure, and stop watch.
- Visual Analog Scales (VAS) were used to measure the following subjective ratings during Stations 2-6:
 - Stability and security of SA or PA components, fastenings, and adjustments,
 - Interaction and operation ease of SA or PA and its components with the ensemble (e.g., helmet, turnout gear, etc),
 - The suitability of SA or PA to participants job related tasks (0:poor – 10:optimal),
 - Any factors of SA or PA that reduced mobility, fit, or comfort during activity just performed,
 - Any perceived restrictions and/or functional limitation of SA or PA on carrying out actions during activity participant just performed.
- Statistics - All data were first calculated and presented as mean and standard deviation for each category of measurements. Static/dynamic ROM and VAS data were analyzed by paired-samples t-test to determine the SA and PA mean differences using a statistical software package. Alpha level was set at p < 0.05.



Figure 3. Participant wearing the PA in Station 3: Window egress exercise



Figure 4. Participant wearing the PA in Station 6: Roof venting exercise

Results

- There was no significant difference in the donning/doffing times (dynamic ROM) when comparing the SA versus the PA.
- There was also no statistical difference detected in subjective ratings on donning/doffing ease.
- In measurements of static ROM, shoulder flexion and trunk extension were greater (gain; p<0.05) for the PA compared to the SA.
- No differences in any cervical or reach measurements were measured.
- Regardless of statistical significance, cervical flexion, trunk flexion and lateral flexion were the only factors measured showing loss of static ROM in the PA compared to the SA.

Results (continued)

- VAS measurements (Figures 5-6) showed that the subjects significantly perceived higher comfort, greater mobility, and less fatigue when they performed the assigned exercises with the PA than SA except the factors as follows; lower body comfort and mobility in reduce profile and SCBA confidence exercises; and fatigue in reduce profile and entanglement exercises.

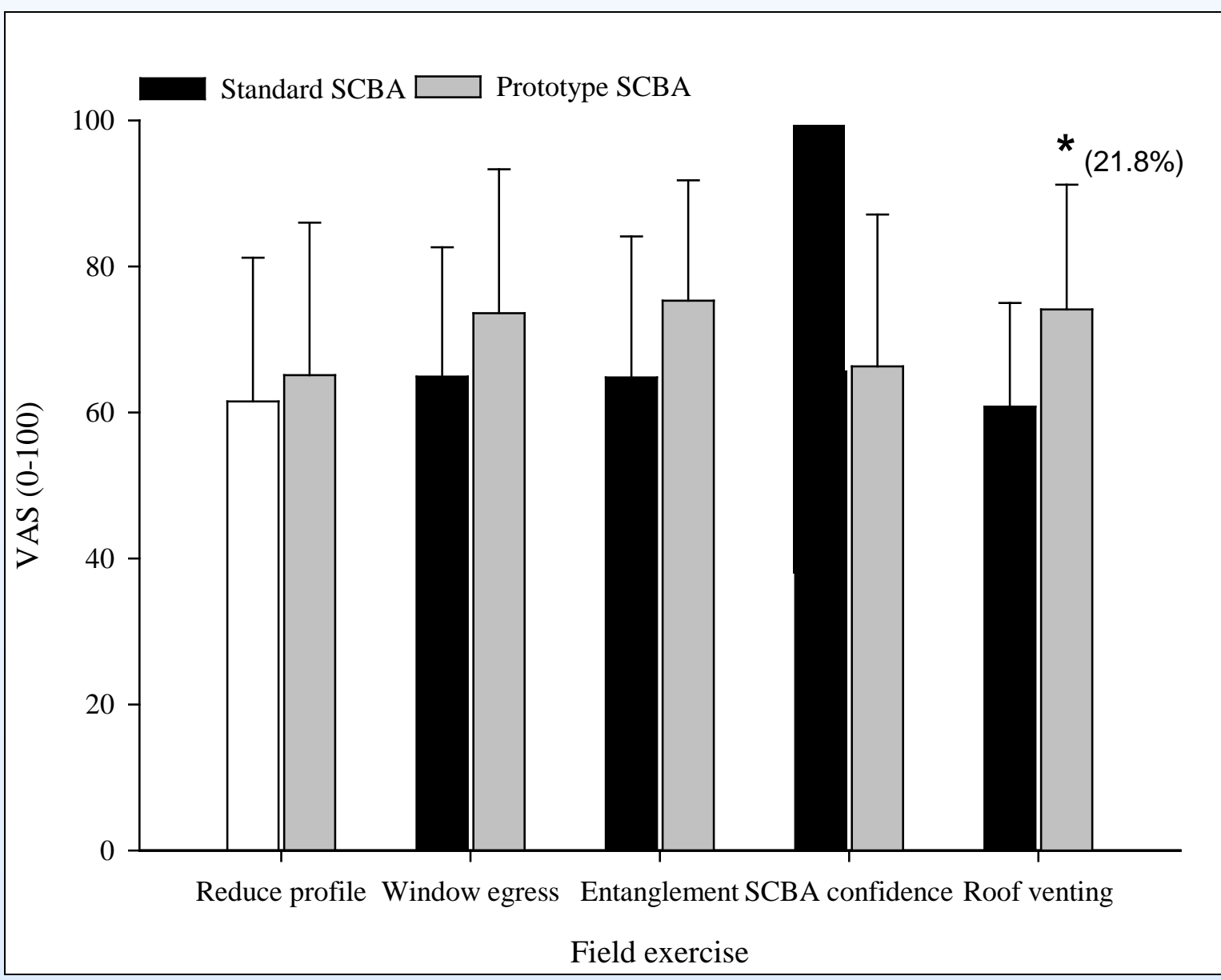


Figure 5. Stability and security of SA or PA components, fastenings, and adjustments. * p < 0.05.

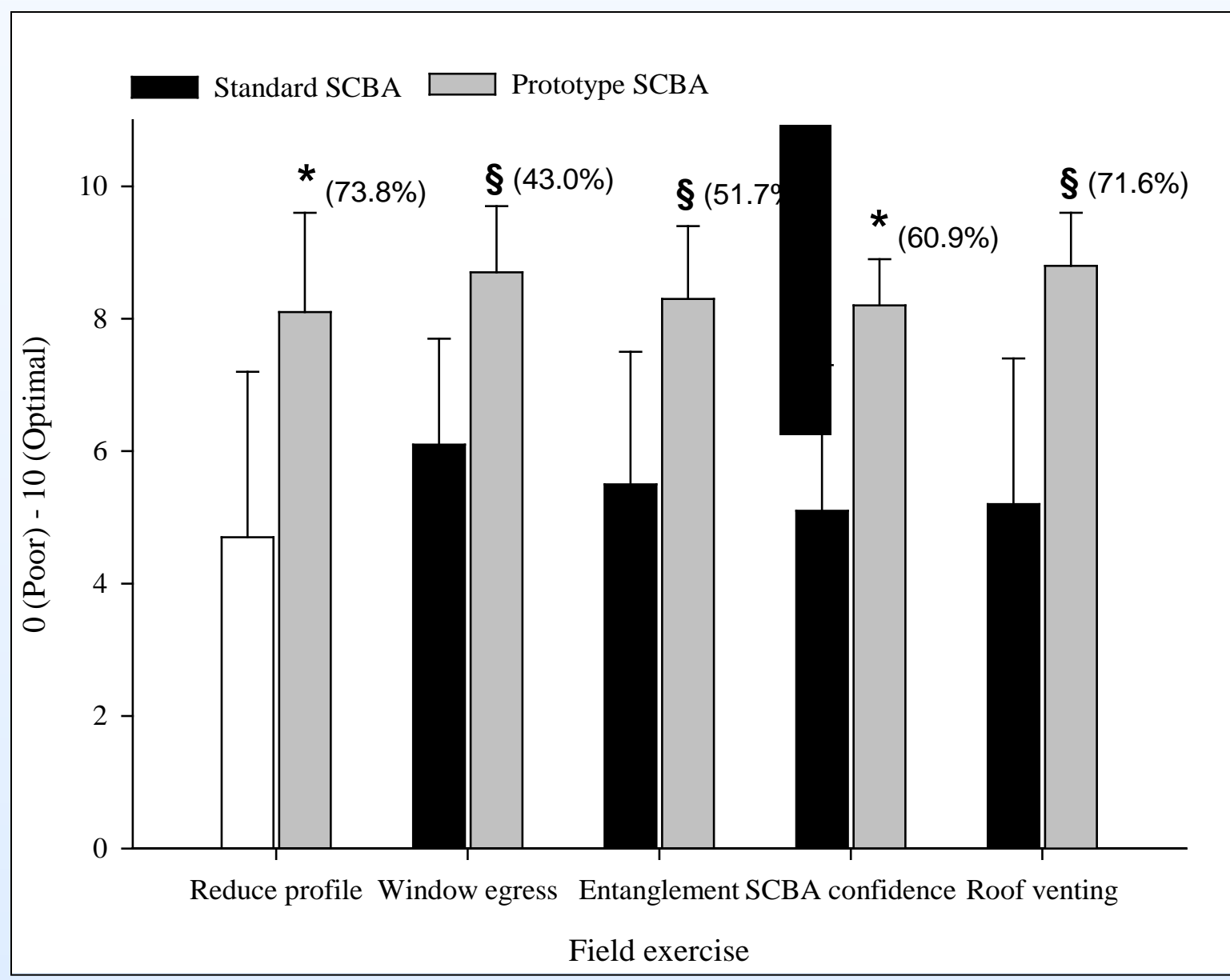


Figure 6. The suitability of SA or PA to your job related tasks (0:poor – 10:optimal). * p < 0.05. § p < 0.01.

Conclusions

- At the onset of the study, it was expected that the new size and design configuration of the PA would not significantly affect users’ functional mobility. However, in the measurements of static ROM, the subjects showed significant gains in shoulder flexion and trunk extension with the PA compared to the SA.
- The more even distribution of the weight and the proximity of the PA on the participants’ back improved subject comfort when extending the trunk, without the outward pull of the weight as occurs with the SA.
- Comfort, mobility, and fatigue:
 - The PA was rated as more comfortable (provided better mobility) compared to the SA.
 - Overall body, upper body, and arm/shoulder comfort was rated to be significantly greater (40 to 90%) in the PA across all exercises performed compared to the SA.
- Study Limitation: because of DOT restrictions, the PA was tested in “uncharged (empty)” condition. Therefore, the results could have been affected by the weight reduction in the uncharged mode. In addition, the study did not perform any scientific measurements or examination of gauge, regulator, facepiece, or air-pressure vessels of the PA.
- The findings of this study can be used for improving the system design and overall performance of new SCBAs for use in the fire service.
- Future studies are needed to develop a standard test protocol for ergonomic evaluations to enhance mobility and function during use.

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